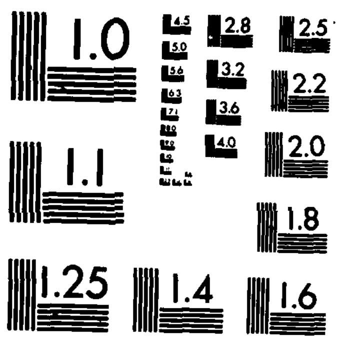
AD-A126 092 WAVE PROPAGATION IN PARTICULATE MEDIA(U) OREGON GRADUATE CENTER BEAVERTON R A ELLIOTT 15 MAR 83 N00014-79-C-0897 1/1

UNCLASSIFIED F/G 20/6 NL

END
FILMED
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A126092	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) WAVE PROPAGATION IN PARTICULATE MEDIA		5. TYPE OF REPORT & PERIOD COVERED Final Report 9/1/79-8/31/82
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Richard A. Elliott		8. CONTRACT OR GRANT NUMBER(s) N00014-79-C-0897
9. PERFORMING ORGANIZATION NAME AND ADDRESS Oregon Graduate Center 19600 N.W. Walker Road Beaverton, Oregon 97006		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR394-045
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research, Physics Program Office 800 N. Quincy Street Arlington, VA 22217		12. REPORT DATE March 15, 1983
		13. NUMBER OF PAGES 6
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Optical scattering, pulse delay, pulse stretching, beam spreading, cloud simulation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The results of experiments to measure the delay, temporal stretching, attenuation, and spatial spreading of optical pulses in scale model clouds are reported. The model clouds consisted of diiodomethane/water or paraffin oil/water emulsions maintained in a rotating scattering cell to prevent settling of the droplets. The optical pulses were 532 nm, 25 ps duration pulses generated by a frequency doubled, passively mode locked Nd:YAG laser and were detected with a 10 ps resolution streak camera. The measurements of the delay in the mean arrival time of the pulses due to multiple scattering are the first ever measured directly.

WAVE PROPAGATION IN PARTICULATE MEDIA

Richard A. Elliott

Final Report

March 15, 1983

Contractor: The Oregon Graduate Center

Sponsor: Office of Naval Research
800 N. Quincy Street
Arlington, Virginia 22217

Contract Number: N00014-79-C-0897

Effective Date of Contract: September 1, 1979-August 31, 1982

Principal Investigator: Richard A. Elliott

Approved for Public Release;
Distribution Unlimited

Wave Propagation in Particulate Media

The purpose of this project was to study optical pulse propagation in a medium consisting of random, discrete scattering centers with a view to establishing the effects of clouds and fog on optical communication systems. The delay in the arrival time, duration, and amplitude of pulses transmitted through the medium and the spatial spreading transverse to the propagation direction were to be measured and compared to the predictions of theoretical models.

An appropriate scattering medium for experiments of this type was found to be emulsions of two dielectric liquids since the indices of refraction of both the scatterers and the bulk medium could be varied by choosing different substances and the size of the droplets of the dispersed phase could be controlled by the method of preparation. In addition, the emulsions could be stabilized with surfactants and have much higher number densities than can be maintained in cloud chambers. This allowed simulation of the effects of kilometers of cloud in a laboratory scale scattering experiment.

The scattering media used for this project were emulsions of either mineral oil or diiodomethane (DIM) in water stabilized with lauryl sulphate as a surfactant. The latter emulsion is of particular interest since the relative index of refraction, 1.74/1.33 = 1.30, is nearly that of water in air and thus simulates scattering in clouds and fog. The preparation technique involved forming a coarse emulsion, passing it through nuclepore filters to refine the droplet size distribution and finally exploiting the differential drift velocity under the influence of gravity of droplets of different radii to further reduce the variance of the size distribution. It was found practical by this means to produce tens of liters of the scattering medium with well controlled parameters.

The parameters determining the single scattering characteristics of these emulsions were determined from direct measurement of the index of refraction of the liquids and the size distribution of the droplets. The diameter of the droplets was obtained by drawing samples from the scattering media, taking microphotographs at 400X and measuring the size of the images. Since the volume of the sample viewed under the microscope was known, the number density of the scatterers and the complete size distribution could be constructed.

The mean and standard deviation of the droplet diameters of the systems studied ranged from d = 1.86 μm, σ_d = 0.85 μm to d = 12.9 μm, σ_d = 3.8 μm. The number density of the scatterers ranged from 3.0×10^{12} to 1.1×10^{14} m^{-3}.

The mean scattering cross section, the mean of the cosine of the scattering angle and the average single scatter albedo were calculated using a computer code for Mie scattering for each of the prepared emulsions. The albedo for all the oil/water systems was unity to six significant figures while for the DIM/water system, the lowest calculated albedo was 0.99926. The inverse of the mean scattering cross section times the number density is the scattering length or optical mean free path, $b = (N\sigma_s)^{-1}$. For the systems studied, b ranged from 0.45 to 3.40 mm. The asymmetry factor $g = 1 - \langle \cos \theta \rangle$ ranged from 0.050 to 0.171. The range of cross sections and number densities available enabled measurements to be made on systems whose optical thickness varied from 0.1 to 170 all in a scattering cell 12 cm long and 40 cm in diameter.

The multiple scattering experiments performed involved the measurement, with a streak camera, of the time delay, stretching and attenuation of 532 nm laser pulses initially of 25 ps duration. The pulses were produced by frequency doubling the output of a passively modelocked Nd:YAG laser. Figure 1 shows a typical streak camera record for a pulse transmitted through 4 cm (optical thickness τ = 63) of DIM/water emulsion.

Figure 2 shows a plot of time delay as a function of optical thickness. The experimental data represents measurements made on two DIM/water emulsions and one oil/water system. The straight line is the behavior predicted by Monte Carlo simulation calculations.[2] The DIM system data agrees much better with the theory than does that of the oil system which has much stronger forward scattering, g = 0.078 compared to g = 0.142 and 0.171 for the DIM systems, indicating that the theory and simulation results do not adequately account for extreme forward scattering.

Figure 3 displays the ratio of the integrated intensity of the scattered pulses to that of the incident pulse for four DIM systems. The dashed line is the Beer-Lambert $\exp(-\tau)$ and the solid line the computer simulation result,[2] $1.69\ (g\tau + 1.42)^{-1}$ multiplied by 10^{-4}. This factor of 10^4 discrepancy between the measured and calculated values is unresolved but may be explained by the fact that the detector was 20 cm from the surface of the scattering cell.

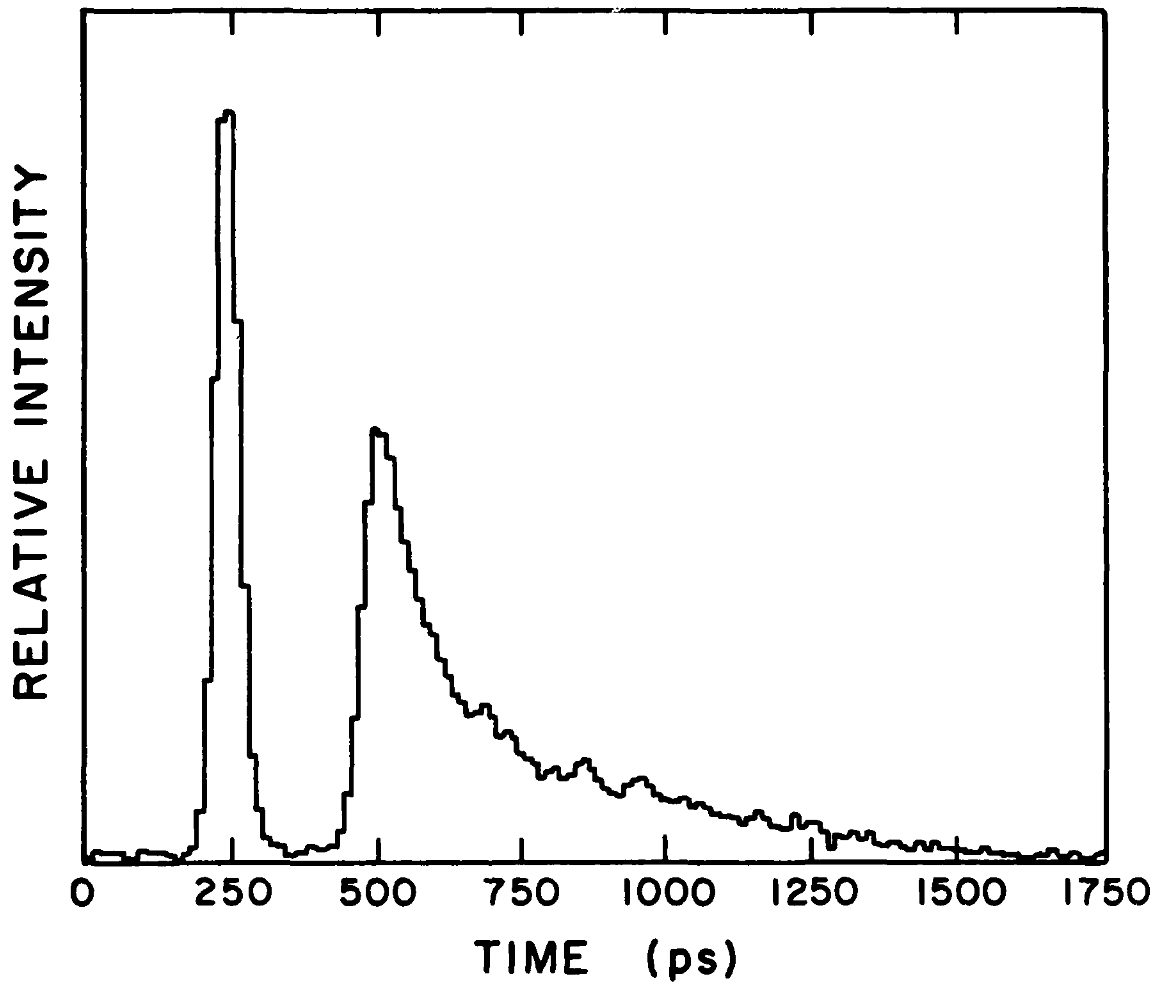


Figure 1. Typical intensity versus time streak camera record. The pulse on the left is a reference pulse which has bypassed the scattering cell. The pulse on the right has propagated through 63 optical thicknesses of a diiodomethane/water emulsion.

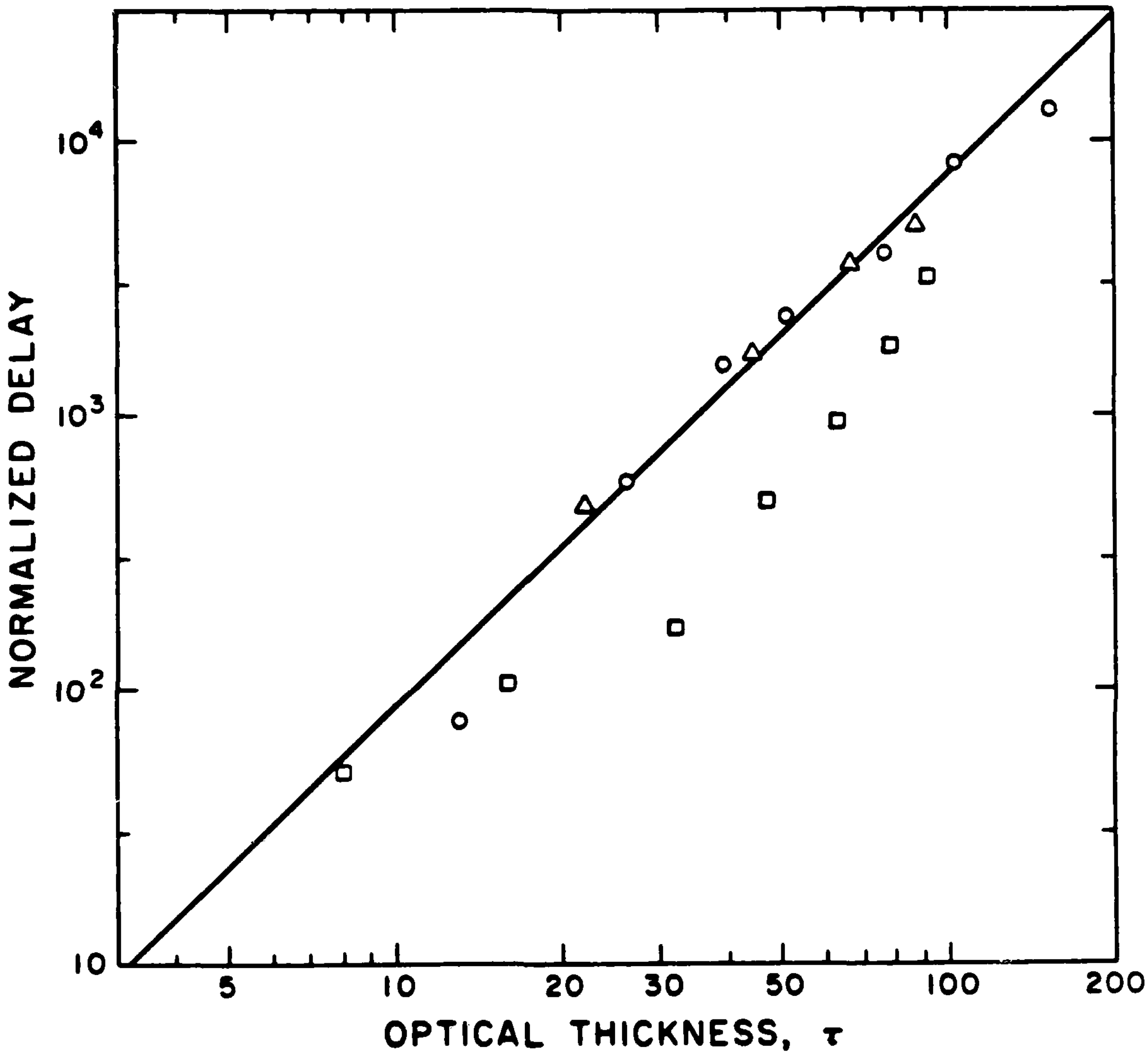


Figure 2. Delay in the mean arrival time due to multiple scattering. Measured delay times have been normalized by multiplying by $c\ b^{-1}\ g^{-0.94}/0.62$, where c is the speed of light, b the scattering length and g the asymmetry factor. ○,Δ – DIM emulsions; □ oil emulsion. The line is $\tau^{1.94}$.

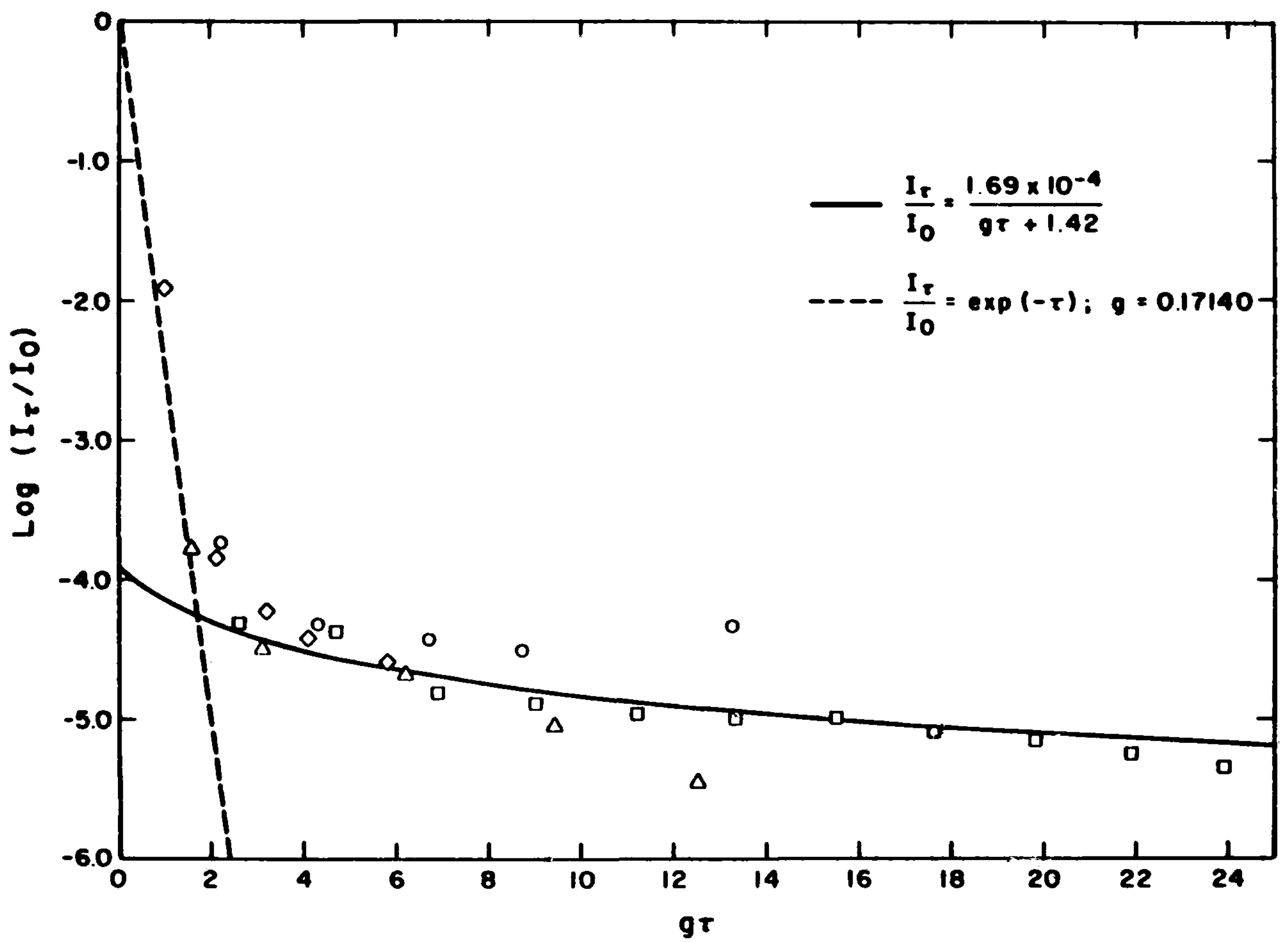


Figure 3. Relative integrated intensity versus optical thickness times the asymmetry factor, gτ, for four DIM emulsions.

The general conclusion which can be drawn from this work is that the computer simulation models[2] of multiple scattering of optical pulses is adequate for describing propagation through clouds and fog and other systems with moderate forward scattering $g \gtrsim 0.1$. Except perhaps that the actual energy loss may be somewhat greater than predicted by the model. Systems exhibiting extreme forward scattering $g \lesssim 0.1$ are not well described by the theoretical model. A more sophisticated model which takes into account higher moments of the scattering function,[1] e.g., $\langle \cos^2\theta \rangle$ might give better agreement with the experiments. However most Mie scattering codes currently in use including the one available for this program do not evaluate higher moments making comparisons with the PSR model[1] difficult.

A complete description of the project and all results including some beam spread and field of view effect measurements are contained in a technical report to be published in Applied Optics under the title "Multiple Scattering of Optical Pulses in Scale Model Clouds." Parts of this work were also reported at the Annual Meetings of the Optical Society of America at Kissimmee, Florida October 19, 1981[3] and Tucson, Arizona, October 21, 1982;[4] at the Conference on Lasers and Electro-Optics, Phoenix, Arizona, April 16, 1982;[5] and at the OSA Topical Meeting on Optical Techniques for Remote Probing of the Atmosphere, Incline Village, Nevada, January 11, 1983.[6]

1. A. P. Ciervo, "Multiple Scattering in Clouds," Pacific Sierra Research Corp., Report 923, September 1979.
2. E. A. Bucher, Appl. Opt. 12, 2391 (1973).
3. J. Opt. Soc. Am. 71, 1603 (1981).
4. J. Opt. Soc. Am. 72, 1787 (1982).
5. CLEO '82 Technical Digest p. 162.
6. Optical Techniques for Remote Probing of the Atmosphere Technical Digest Paper TuC3.

END

FILMED

4-83

DTIC